International Journal of Biology and Biological Sciences Vol. 5(2), pp. 009-016, May 2019
Available online at http://academeresearchjournals.org/journal/ijbbs
ISSN 2327-3062 ©2019 Academe Research Journals

Full Length Research Paper

Litter Dynamics (Production and Composition) in *Vitex doniana, Terminalia avicennioides, Sarcocephallus latifolius* and *Parinarri curatellifolius* in Makurdi, Benue State, Nigeria

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Accepted 5 May, 2019

Litter fall rate, composition and accumulation in *Vitex doniana, Terminalia avicennioides, Sarcocephallus latifolius* and *Parinarri curatellifolius* were investigated at the Agan forest, Makurdi, Benue State, Nigeria (November, 2015 to October, 2016). Litter fall rate and accumulation on the floor were measured using litter traps and quadrats while carbon content in litter was determined as 50% of biomass. Litter fall and composition varies significantly ($p<0.01$) with species and months, mean total litter fall was 68.04 (g m^{-2}) with leaf litter contributing the most (44.39%), while *V. doniana* (101.19±30.98 g m^{-2}) and *T. avicennioides,* (30.31±6.84 g m^{-2}) have the highest and lowest amounts of total litter. There was seasonality in litter production between December (102.60 g m^{-2}) and July (177.53g m^{-2}). Mean total litter biomass was 91.35(g m^{-2}) with leaf contributing about 37.03(g m^{-2}). *V. doniana* (184.48 g m^{-2}) and *T. avicennioides* (39.20 g m^{-2}). Litter fall correlates positively with plant height (r =-0.274, R^2= 0.075, p=0.0243) and crown diameter (r =-0.517; R^2=0.0267, p=0.020). litter turnover rate ranged between *P. curatellifolius* (1.01) and *V. doniana* (0.55), while residence time was between *V. doniana* (1.82) and *P. curatellifolius* (0.99). Carbon sequestered in plant litter (tones/ m-^{2} y^{-1}) varied significantly ($p<0.01$) among species, with the highest and lowest values in *V. doniana* (0.186, 0.339) and *T. avicennioides* (0.055, 0.072) for litter fall and litter biomass respectively.

Key words: Litter production, litter trap, turnover rate, residence time, litter biomass, *Vitex doniana, Terminalia avicennioides, Sarcocephallus latifolius* and *Parinarri curatellifolius*

INTRODUCTION

Litter fall measurement is an indirect way to estimate net primary productivity and a useful tool in environmental impact assessment and ecosystem management (Clark *et al*., 2001; Kushwaha and Singh, 2005). Litter fall is the major pathway for organic matter and nutrient return from plants to the soil (Saha *et al*., 2016; Bargali *et al*., 2015; Becker *et al*., 2015; Odiwe and Muoghalu, 2003). Edu *et al.,* (2014) reported that evaluation of species litter production is key to understanding productivity and carbon credits, hence studies on litter composition and amounts are essential for species conservation. Fallen litter also protects the underlying humus and mineral against drought and acts as a buffer improving the ecosystem capacity (Deng and Janssen, 2006). Zhang *et al*. (2008) explained that litter fall is characteristic of tropical ecosystems. The balance between litter production and decomposition determines organic matter accumulation in any ecosystem (Singh *et al.* 2004, Triadiati *et al*. 2011 and Valentini *et al*. 2000).

Litter production varies in amount and composition, with species ecological habitat (climate), vegetative phenology, stand structure as well as soil fertility (Liu *et al*., 2004; Gwada and Kairo, 2001 and Cattanio *et al*., 2004). Also, mixed forests have been reported to have greater litter fall rates than mono-specific stands, while litter fall magnitude is greater in mangrove than in upland forests (Saenger and Snadaker, 1993 and Cattanio *et al*. 2004). According to Robertson and Paul (1999), litter fall

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in forest consist of about 70% leaf and 30% wood, propagules and flowers. This study therefore seeks to evaluate productivity using litter production in the selected species of the Guinea savanna ecosystem in Makurdi, Benue State Nigeria. While the specific objective is to investigate the temporal variation in species litter production and composition and compare with other tropical ecosystems of the world.

MATERIALS AND METHODS

Study Area

The research was carried out in Makurdi, Benue State. The area falls within the Southern Guinea Savanna agro ecological zone of Nigeria and lies within latitudes 70 38' and 70 50' North of the Equator and longitude 80 24' and 80 38' East of the Greenwich Meridian. The relief is generally low lying, ranging from below 90 m to 150 m above sea level with three soil types (alluvial, clayey loam and sandy), and covering a total land mass of 3,993.3 Km2 and divided by the River Benue into North and South Banks (Kogbe, 1989; Tyowua et al., 2013).

The region is a tropical area with alternating wet and dry seasons having an average annual precipitation of 1240-1440 mm (NIMET, 2015, 2016). The wet season lasts for about seven months (April- October), while the dry season runs from November – March (five months). Temperature is generally high during the day especially in March and April, with daily maximum and minimum temperatures between 37 ^{0}C and 16 ^{0}C (NIMET, 2015, 2016).

The vegetation of the area is the Guinea Savanna type, typified by continuous cover of tall grasses with trees occurring in patches or discontinuous clusters, probably resulting from low rainfall in the area, long term anthropogenic disturbances such as farming, annual bush burning and lumbering. Consequently, the resulting vegetation is a mixture of natural and human managed mosaics of different shape, size and structure (Abah, 2013, Tyowua *et al*., 2013).

Litter fall and Litter Biomass (Standing Crop)

Leaf litter was collected monthly, using litter traps (1 m^2). Each litter trap consisted of four sided wooden frames staked on four wooden stands (1 m each) with 1 mm nylon mesh. The nylon mesh was fitted into the frame and allowed to sag downwards forming a receptacle that prevented other vegetative structures from bouncing off. A total of 40 litter traps were used (one trap per plant).

Seasonal rates of litter fall for all species were investigated for a period of 12 months (covering dry and wet seasons; from November, 2015 to October, 2016). The trap contents were harvested at monthly intervals, to minimize leaching or decomposition of leaves within the traps. Litter collected were emptied into clean, labelled polyethylene bags, taken to the laboratory and sorted into 3 categories (leaf, wood and miscellaneous-flowers, fruits). The leaves were dried to constant weight at 80 ^{0}C for 12 hours in a Gallenkamp (England) drying oven to the nearest 0.1 g.

Litter biomass (standing crop) on the floor was determined by placing a 1m^2 quadrat on the floor of each species. The litter collected within the quadrat were harvested monthly and processed as described above for litter fall.

Sequestered Carbon in Plant Litter

The sequestered carbon in plant litter was determined as 50% of total litter fall and litter biomass (dry weight) collected, based on the general assumption that carbon content in plants is 50% of dry plant material (Losi *et al*., 2003; Jana *et al*., 2009). Sequestered carbon dioxide equivalent (SCO_2E) was determined by multiplying carbon in plant biomass by a carbon correction factor (3.67).

One-way analysis of variance (ANOVA) was used to evaluate differences between species total sequestered carbon in plant biomass in the eight species.

The effects of species and months on total sequestered carbon in total litter fall and total litter biomass were evaluated using a two-way multivariate analysis of variance (MANOVA), with species and months as the main factors.

Litter turnover rates

Actual turnover rates for all litter components based on relative measures of litter fall and leaf biomass were evaluated using Equation (1) (Nye 1961).

$$Kt = L/X$$

Where L = Litter fall
X = Steady state of litter on the floor.
Kt = Litter turnover

Data Analysis

All data were analysed statistically using Predictive Analytical Soft Ware package (SPSS) version 21.0 software for windows.

Litter fall and litter biomass

A two-way multivariate analysis of variance (MANOVA) was used to evaluate total litter fall and litter biomass and their individual components for the species with species and months as the main factors. The rates of litter fall and litter biomass were computed for each species and presented as graphs with litter fall (g m^{-2}) plotted against time (months).

The Tukey honest significant difference (Tukey HSD) was used to test the level of significant differences between the means (means that were not statistically different were ranked with similar letters).

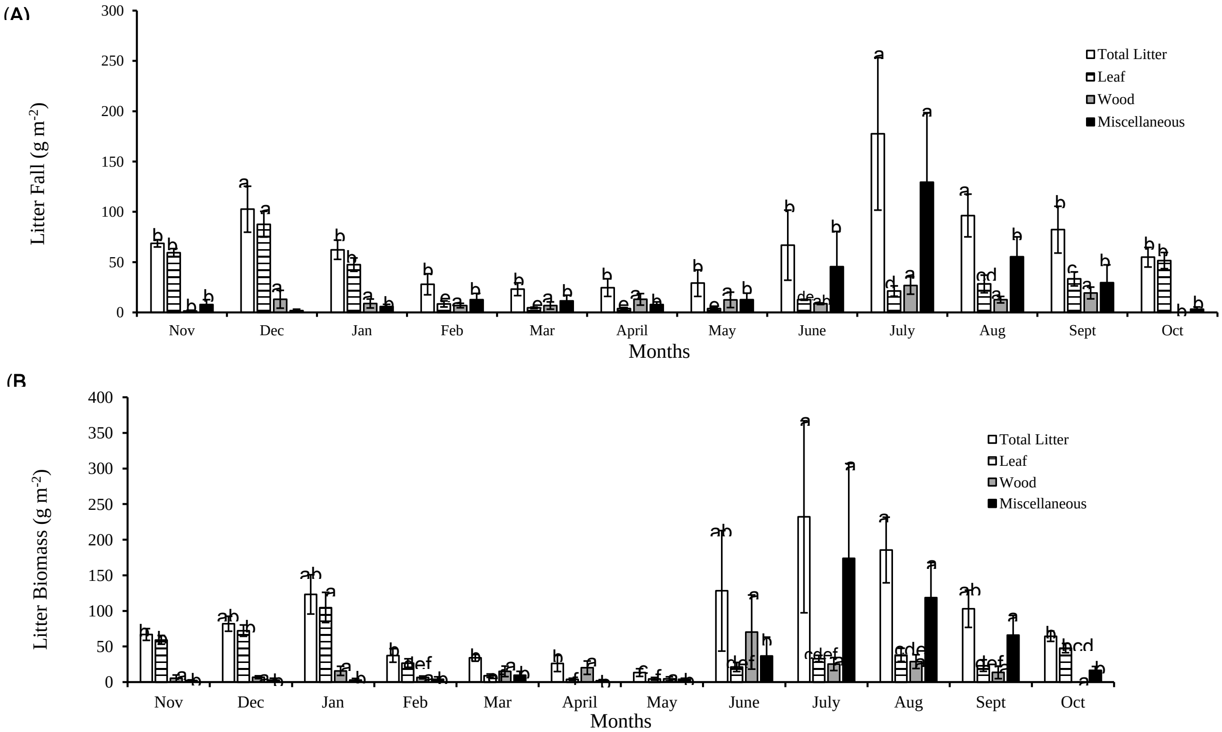

Figure 1. Mean Monthly Litter Production across four species. (**A**) Litter Fall (**B**) Litter Biomass. Vertical bars represent means. Means with the same alphabet are not statistically different from each other P>0.05

Relationships between plant parameters (plant height, diameter at breast height and crown diameter), litter fall and litter biomass were evaluated using correlation and regression analyses.

RESULTS

Litter fall

Monthly rates of litter fall, mean total litter fall as well as litter composition (leaf, wood and miscellaneous) in all the species within the study period are presented in figure1 and 2. The average monthly litter fall was 68.04 (g m^{-2}) across species, with leaf litter accounting for 44.39% (30.20), wood litter 15.96% (10.86) and miscellaneous litter 39.65% (26.98). A two-way multivariate analysis of variance (MANOVA) revealed highly significant differences (P<0.01) in rates of litter fall, litter composition and interaction across months and species. Mean monthly total litter fall exhibited seasonality with bimodal peaks in December (102.60±22.28) and July (177.53±75.82); while among species, mean monthly total litter fall was highest in *Vitex doniana* (101.19 ±30.98) and lowest in *T. avecinioides* (30.31±6.84). Figure 1). Litter fall correlates positively with plant height and crown diameter (r=0.274, 0.55), indicating that larger trees produce more litter (Table 1).

Litter Biomass

Mean monthly total litter biomass accumulation on the floor within the study period was 91.35 (g m^{-2}), with leaf litter contributing 37.03 (40.54%); wood litter, 17.70 (19.38%) and miscellaneous litter, 36.61 (40.08%) respectively (figure 1b).

MANOVA revealed significant variations (p<0.01) in composition and quantity of litter biomass with bimodal peaks in January (123.24±134.94) and July (232.24±134.94). Average monthly litter biomass was highest in *V. doniana* (184.48±54.84) and lowest in *T. avecinioides* (39.20±6.92). Litter biomass on the floor correlates negatively with plant height and crown diameter (r=-0.107, -0.11), indicating that larger trees produce less litter (Table 1).

Litter Turnover

Litter turnover based on relative measures of litter fall to litter biomass on the floor of each tree are presented in Figure 3. The mean litter turnover rate for all species was (0.83). *P. curatellifolius* had the highest turnover rate (1.01) whereas *V. doniana* had the least (0.55) turnover rate.

Sequestered Carbon in Plant Litter

The sequestered carbon in plant litter significantly varied (p<0.01) with species litter fall and litter biomass. *V. doniana* recorded the highest sequestered carbon dioxide (0.186, 0.339 tones/ m^{-2} y^{-1}) while *T. avecinioides* (0.055, 0.072 tones/ m^{-2} y^{-1}) had the lowest estimates, in litter fall

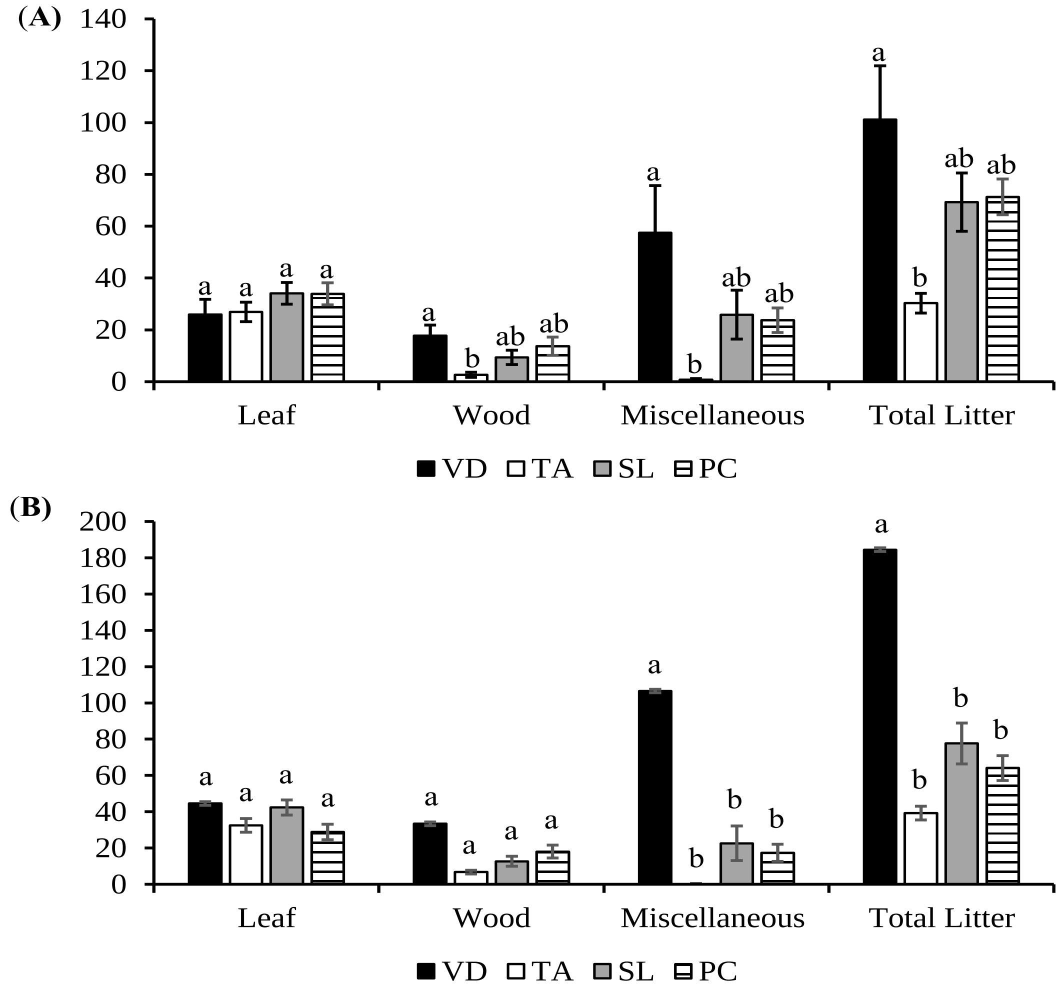

Figure 2. Litter composition in the four species (**A**) Litter fall (**B**) Litter Biomass. VD: *Vitex doniana*; TA: *Terminalia avicennioides*; SL: *Sarcocephalus latifolius*; PC: *Parinari curatellifolia*. Vertical bars represent means. Means with the same alphabet are not statistically different from each other P>0.05.

Table 1. Correlation and regression coefficients and equations showing relationship between litter production and plant parameters

Comparison	Pearson Correlation r	R^2	Strength of Correlation	p value	Equation
Height v Litter Fall	0.274	0.075	Weak positive	0.243	y = 7.01+0.03*x
Height v Litter Biomass	-0.107	0.011	Weak negative	0.652	y = 10.51+-0.02*x
Crown Diameter v Litter Fall	0.517	0.267	Moderate Positive	0.020*	y = 4.07+0.03*x
Crown Diameter v Litter Biomass	-0.11	0.012	Weak negative	0.644	y = 7.18+-0.01*x

*P < 0.05

and litter biomass respectively (Figure 4). MANOVA indicates significant differences (p<0.01) between total sequestered carbon in litter fall compared to litter biomass in all the plant species.

DISCUSSION

Litter Production

Litter fall composition within the study period with leaves accounting for 45.13%, wood (22.19%) and miscellaneous litter (32.68%) of the total litter fall (Figure, 1) is comparable to litter composition in other tropical systems as reported by other researchers (Edu *et al*., 2014, Odiwe and Muoghalu, 2003;). Also, the seasonality observed with peaks in December (102.60 ± 22.28 g m^{-2}) and July (177.53±75.82 g m^{-2}) is the general pattern of litter fall in the tropics (Mfilinge *et al*., 2005; Valenti *et al.,* 2008; Edu *et al*., 2014 and Chave *et al.*,

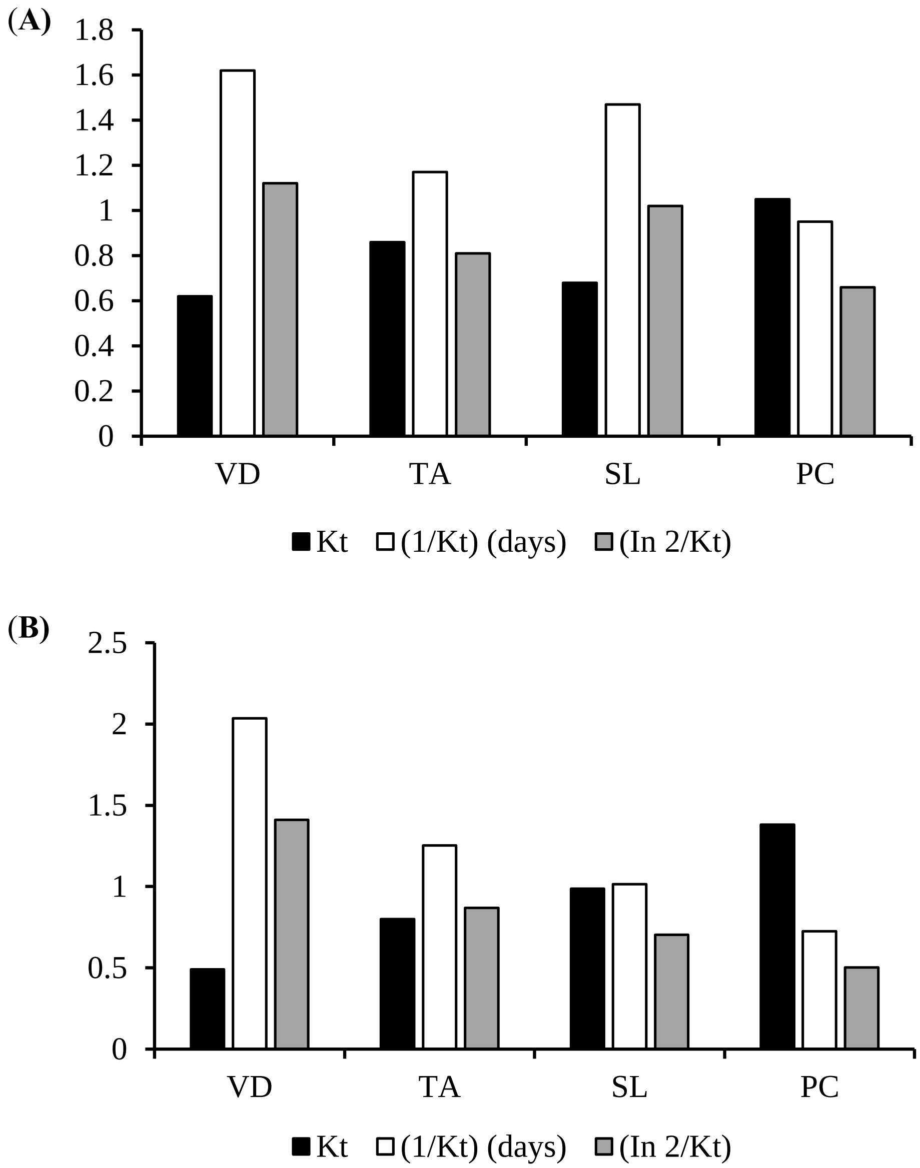

Figure 3. Litter Turnover Rate(Kt), residence time(1/kt) and Half-life (T_{50}=Ln2/kt) (**A**) dry season (**B**) wet season. VD: *Vitex doniana*; TA: *Terminalia avicennioides*; SL: *Sarcocephalus latifolius*; PC: *Parinari curatellifolia*.

2010). The litter fall pattern may be attributable to influences of environmental variables (rainfall, temperature and wind speed) in the study site, since the area is located in a humid Savanna ecosystem with two marked seasons; a windy, hot and dry season and the humid wet season.

Variation in species mean monthly rates of litter fall with highest rate in *V. doniana* (101.19±30.98 g m-2) and lowest rate in *T.avecinioides* (30.31±6.84 g m-2) suggests that litter fall was influenced by plant size, species leaf architecture and ornamentation as well as chemical composition (lignin content).

Mean monthly litter biomass of 91.35 g m-2 (Figure 1b) was higher than mean monthly litter fall of 68.04 g m-2 suggesting litter retention on the floor and the possibility of litter accumulation from large or extensive branches which would have escaped the litter traps and aggregated on the floor. The seasonality exhibited in the mean rate of litter biomass accumulation on the floor (123.24±27.68 g m^{-2} in January and 232.24±134.94 g m^{-2} in July) indicates higher litter fall in the rainy season than in the dry season and the absence of other mechanisms of litter export (surface run-off, macro and micro consumers) from the floor during the period. The wet season peaks in litter fall recorded in this study is probably due to the absorption of water by dead plant parts on the trees during the rainy season which increased their weight and their subsequent abscission or removal from trees and the force of the strong winds which accompany rains during the rainy season (Dawoe

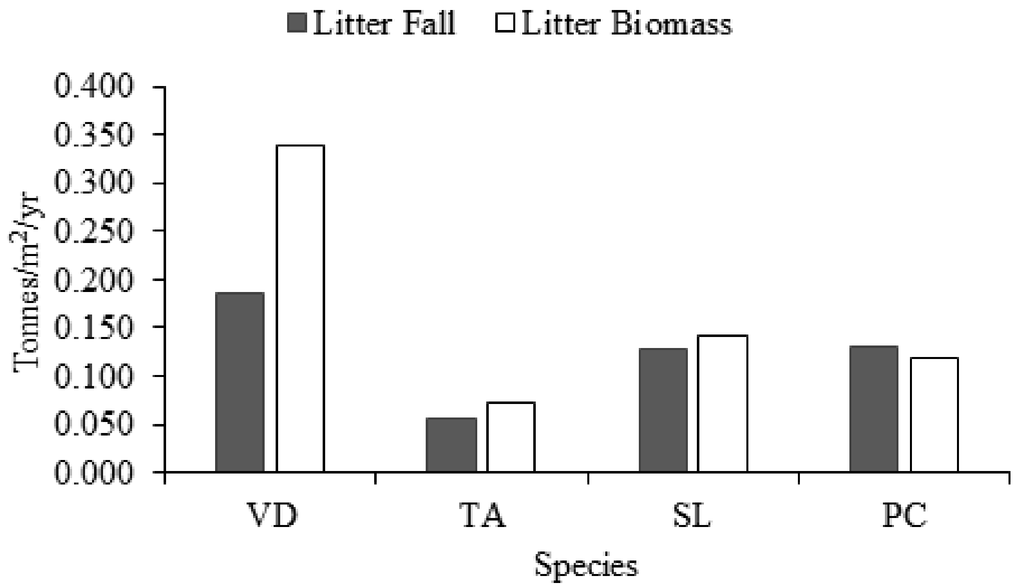

Figure 4. SCO_2E in Plant Litter (Litter Fall and Litter Biomass) for four species. VD: *Vitex doniana*; TA: *Terminalia avicennioides*; SL: *Sarcocephalus latifolius*; PC: *Parinari curatellifolia*.

et al., 2010; González-Rodríguez *et al*., 2011). Another explanation to wet season litter fall according to de Wiedt *et al*. (2012) is that, when a new leaf is produced, less efficient leaf will shed to enhance canopy photosynthesis.

The positive relationship (Table, 1) between litter fall, plant height and crown diameter in this study indicates that, litter fall increases with increasing height and crown diameter. This means that plant height and crown diameter may be used to predict litter fall pattern especially on tree stand basis.

Murali and Sukumar (2001), Bhat and Murali (2001); Okeke and Omaliko (1994); suggested that leaf fall (shedding of leaves) is a phenological behaviour in woody species especially in the dry season in response to environmental stress (drought) and physiological senescence. Reports by Muoghalu (2004); Odiwe and Muoghalu (2003) and Isaac and Nair (2006) further explained that high evapotranspiration in the dry season exceeds rainfall leading to water stress or reduced moisture, excessive dryness and salt stress. Dawoe et al. (2010) and Yang et al. (2003) further explained that reduced humidity and lower night temperatures in the dry season may stimulate production of abscisic acid in the plant leaves which stimulate leaf fall.

Röderstein *et al.* (2005) also stated that senescence due to photo-inhibition and stomata closure contributes to leaf shedding in the dry season. De Wiedt *et al*. (2012) stated that leaf fall is an adaptive mechanism by trees to utilize their photosynthetic capacity which enhances their competitive ability in a crowded forest. The plants therefore attempt to reduce the cost of maintaining less productive (photosynthetic) aged leaves through senescence, hence the high litter fall peak in the period.

Sequestered Carbon in Plant Litter

The sequestered carbon in plant litter (tones/ $m^{-2}y^{-1}$) significantly varied ($p<0.01$) with species litter fall and litter biomass. *V. doniana* had the highest sequestered carbon in litter fall and litter biomass (0.186; 0.339 tonnes m^{-2} y^{-1}), while *T. avecinioides* had the lowest (0.055; 0.072 tones m^{-2} y^{-1}), implying that carbon accumulation in litter is species specific. *Vitex doniana* lost more carbon while *T. avecinioides* retains more of its carbon than every other species studied. Carbon stock in litter represents the rate and pattern of annual carbon loss from the plant and gives an insight into the biogeochemical cycling and carbon sequestration as litter return to the soil is the available plant part for decomposition and nutrient release into the ecosystem. Hence the fate of sequestration depends on the relative rate of litter export (loss) from the soil surface. There was also more carbon accumulation in litter fall than in litter biomass, reflecting the variation in litter amounts between the two methods of litter collection and the existence of ecological factors (macro-consumers, wind and surface run-off) that export litter from the soil and their effect on carbon storage.

Litter Turnover

The high litter turnover rate recorded in this study (Figure) implies that litter is lost faster from the forest floor. This has implication for nutrient cycling, carbon sequestration; less biomass accumulation on the floor for decomposition and release into the environment.

Differences among species turnover rate reflect differences in species litter fall and litter accumulation on the floor.

CONCLUSION

Litter production as revealed in this study provides a general knowledge on biomass loss and the pathway of biogeochemical sequestration and indicates the carbon storage capacities of the species and the study area at large. Carbon loss through plant litter was highest in *Vitex doniana* annually compared to other species.

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